Creep and Shrinkage Effects of Prestressed Concrete Cable-stayed Bridge During Segmental Construction

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Abstract. During segmental construction of prestressed concrete cable-stayed bridges, the age-adjusted effective modulus method is used to perform the structural analysis. The effect of creep and shrinkage is converted into equivalent nodal loads by the linear creep theory. Loss of prestress and the effect of ordinary tendon are considered in the derivation. The effect of tendon is calculated using the limit equilibrium method. A calculation procedure is programmed via the above-mentioned method for analyzing construction process of cable-stayed bridges. The Hemaxi bridge, built recently in China is then taken as a case study. The study shows the measured data of elevations of some sections agrees well with the results of the calculation procedure. This demonstrates the proposed method is efficient and reliable.

Introduction

Long span prestressed concrete cable-stayed bridges are usually constructed segmentally. As the main girder extends and the cables are tensioned, the structure becomes increasingly sensitive to the influence of various factors in the construction process, which makes the mechanical analysis of cable-stayed bridges more complicated than the common bridges.

For a long span prestressed concrete cable-stayed bridge, the creep and shrinkage effects of concrete are also needed to be considered apart from the geometrical nonlinearity. Bazant and Neville et al. have carried out a great amount of research work on this topic, and plenty of research results have been achieved [1, 2]. With the extensive application of the prestressed concrete structure, researchers come to find that the influence of concrete creep on the prestressed structures is significant, including the loss of prestress, the internal force redistribution and so forth. During the segmental construction process, the concrete age of each segment unit is different. The cables play a role of elastic supports of the main girder, therefore, the number of statical indetermination becomes larger as the segmental construction goes on. The increment of creep and shrinkage deformations caused by the stress inheriting from the early stage is restrained by the later structures, and then it leads to the variation of the structural internal force. Hence, the influence of creep and shrinkage of concrete must be taken into consideration in the calculation so as to estimate the possible hazards, and provide the basis for the construction camber.

Prestressed concrete cable-stayed bridges are high statical indetermination structures, therefore, creep and shrinkage effects in the process of construction can not only cause
deformation, but also lead to internal force redistribution. The original methods of creep calculation are differential equation method and algebraic equation method, which are replaced by finite element method soon due to the inaccurate assumption and less computational efficiency. The widely used methods for creep calculation are initial strain method [3] and effective modulus method [4]. This paper uses the age-adjusted effective modulus method and the step-by-step finite element method to calculate the creep and shrinkage effects in the construction process of concrete cable-stayed bridges.

**Calculation of Creep**

A large number of experimental studies show the creep behavior is mainly linear when the stress level of concrete is small ($\sigma_c < (0.4\sim0.5)f_c$). The creep caused by the load increment at some moment has nothing to do with the creep caused by the previous load, and the superposition principle is valid. The superposition principle is first applied to concrete creep theory by McHenry (Mchenry 1943). Since the working stress satisfy $\sigma_c < (0.4\sim0.5)f_c$ during bridge construction, the linear creep theory is mainly used, and its calculation precision can satisfy the engineering demand in general.

When analyzing the creep effect of construction stage, the construction process is divided into a number of time intervals $\tau_i$. According to literature [5], the force of beam end caused by creep can be given by

\[
\{F_{ci}\} = \gamma(\tau, \tau_i)[K_i][\delta_i] - \gamma(\tau, \tau_i)[\gamma(\tau, \tau_i)[K_i][\delta_i]]
\]

Where $\{F_{ci}\}$ is the total forces of beam end caused by creep with respect to the $i^{th}$ time interval; $[K_i]$ is the elastic stiffness matrix with respect to the $i^{th}$ time interval; $\{\delta_i\}$ and $\{\delta_{0i}\}$ are the total creep and elastic deformations with respect to the $i^{th}$ time interval, respectively.

**Calculation of Shrinkage**

The shrinkage effect of concrete can also be converted to equivalent nodal load. For beam and link elements, the shrinkage strain along the depth of section is consistent. Hence, the equivalent nodal force caused by shrinkage only includes the axial force, which can be given by

\[
F_i = E A \Delta \varepsilon_i \quad (i)
\]

Where $E$ is the elastic modulus; $A$ is the sectional area; $\Delta \varepsilon_i$ is the shrinkage strain increment of the $i^{th}$ time interval.

**Influence of Prestress Loss and Ordinary Tendon on the Calculation of Creep**

**Calculation Method**

In this paper, the limit equilibrium method is used to consider the interaction between the prestressed tendon and concrete creep, the ordinary tendon and concrete creep. The basic idea is as follows:

(1) Calculate the nodal displacement of concrete structure (not include tendons) caused by the creep (or load increment) of plain concrete at any moment $t$;

(2) Based on the nodal displacement, calculate the axial tension increment of the prestressed tendon by using the deformation compatibility conditions;
(3) Convert the axial tension increment to the equivalent nodal load;
(4) Calculate nodal displacement caused by the equivalent nodal load;
(5) Repeat steps (2)-(4), when the nodal displacement variation is within the
tolerance, the nodal displacement caused by the creep (or load increment) at time \( t \) is
obtained by superimposing each calculation.

**Calculation Process**

Take the analysis of the interaction between the prestressed tendon and concrete creep
as an example. An eccentric reinforced beam is shown in Fig.1. Separating the
prestressed tendon from concrete, the linear creep strain increment in the concrete
center is \( \varepsilon_0 \) at time \( t \), while the angular strain increment is \( \xi_0 \). Fig. 1 shows the
calculation flow.

![Fig. 1. Creep analysis considering the loss of prestress.](image)

**Case Study**

The Hemaxi bridge, built recently in Zhuhai China, is taken as a case study, shown in
Fig. 2. It is a prestressed concrete low-pylon cable-stayed bridge with double pylons.
The pier, girder and pylon of the main span are consolidated. The girder is a
three-dimensional prestressed concrete structure, which is fully prestressed. The 0#
segment of the girder is 18m long, the standard segment is 4m long, and the three
closure segments are all 2m long. As the main girder extends, the length and weight of
the total cantilever segments can reach 114m and 2900kN, respectively. The
construction period of each segment is about 13days.

![Fig. 2. The general view of Hemaxi Bridge (units: m).](image)

The calculation procedure is programmed based on the proposed method. The
following work is concerning he displacements variation of 6#-10# sections during the
construction of 11# to 20# segment. The displacements of each section are shown in
Fig.3.
From Fig. 3, it can be observed that the errors between the calculated and measured displacements are very small, and the varying laws are identical. Some uncertain factors exit in the test process and the different creep coefficients are used in different standards, that is to say, some errors are inevitable, therefore, it indicates the proposed method is efficient and reliable.

Conclusion
The age-adjusted effective modulus method is used to calculate the creep of concrete cable-stayed bridges. The results of a case study show the measured data of elevations some sections agrees well with those of the calculation procedure. This demonstrates the proposed method is efficient and reliable, and it has a great application prospect in the construction analysis of prestressed concrete cable-stayed bridge.

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References